



AEROSPACE INFORMATION REPORT

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SELECTING SLIPPER SEALS FOR HYDRAULIC-PNEUMATIC FLUID POWER APPLICATIONS

1. PURPOSE

The purpose of this report is to provide the design and maintenance engineer with basic information on the use of SLIPPER SEAL sealing devices as piston (O. D.) and rod (I. D.) seals in aircraft fluid power components such as actuators, valves and swivel glands.

2. SCOPE

The SLIPPER SEAL is defined and the basic types in current use are described. Guide lines for selecting the type of Slipper Seal for a given design requirement are covered in terms of friction, leakage, service life, installation characteristics and interchangeability.

3. REFERENCES

MIL-G-5514 Revision F	Gland Design; Packings, Hydraulic, General Requirements For
MIL-P-5514 Revisions A through E	Packings; Installation and Gland Design, Hydraulic, General Requirements For
MIL-R-8791C	Retainer, Packing, Hydraulic, and Pneumatic, Tetrafluoroethylene Resin
AS 568	Uniform Dash Numbering System For O-Rings
MS28774	Retainer, Packing Backup, Single Turn Tetrafluoroethylene
MS28782	Retainer, Packing, Backup, Teflon
MS28783	Ring, Gasket, Back-up, Teflon
ARP 1233 <u>Proposed</u>	Gland Design, Elastomeric O-Ring Seals Dynamic Radial

4. INTRODUCTION

- 4.1 What is a Slipper Seal? It is a separate circumferential band of TFE fitted to either the inside diameter (I. D.), outside diameter (O. D.) or face of a rubber O-Ring or other shape of so-called "squeeze type" molded packing. The cross section of the Slipper Seal configuration can be a variety of symmetrical or asymmetrical shapes (See Figure I).



FIGURE I. TYPICAL SLIPPER SEALS

The combination of a Slipper Seal and molded packing, when fitted in a gland, act together to prevent fluid leakage. When used in a static application, the Slipper Seal prevents extrusion of the elastomer. When used in a dynamic application the Slipper Seal reduces breakout and running friction and protects the elastomer from extrusion and wear.

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The Slipper Seal concept became practical with the availability of Polytetrafluoroethylene (TFE) resins. The first TFE Slipper Seals were probably used successfully around 1950. Polytetrafluoroethylene is a chemically inert, temperature resistant (useful mechanical range 450 F to 500 F) low friction, thermoplastic fluorocarbon plastic compatible with all industrial and military fuels and hydraulic fluids in commercial use.

Although TFE is not elastic in the same sense as rubber material, it is deformable for good sealing and can be stretched and folded for ease in installation. Because TFE is a plastic, sealing surfaces must be protected from scratches and nicks during handling and installation. Installation tools for both O. D. and I. D. Slipper Seals can be used to advantage where one-piece glands are involved, but are not always necessary (see paragraph 9).

Most Slipper Seal commercial standards are designed for use with AS 568 O-Ring sizes in glands per MIL-P-5514. Other types of commercial standards are also available. No MS standards have been issued for Slipper Seals.

4.2 How does the Slipper Seal Work? The performance characteristics of the O-Ring as a dynamic or static seal is assumed to be familiar to the reader. An O-Ring used in a dynamic application is exposed to extrusion, spiral failure and wear and will have a relatively short life compared to an O-Ring used as a static seal in an otherwise equal environment.

When O-Rings are used with back-up rings such as MS28774, the O-Ring is protected against extrusion but is still vulnerable to the effects of friction which causes spiral failure and wear. An O-Ring used with a Slipper Seal in a dynamic environment, becomes a static seal, and is protected from the effects of friction as well as extrusion.

By definition a Slipper Seal is not a complete seal until it is used in combination with squeeze-type elastic packing seal such as an O-Ring. Figure II shows the simplest of all Slipper Seal constructions.

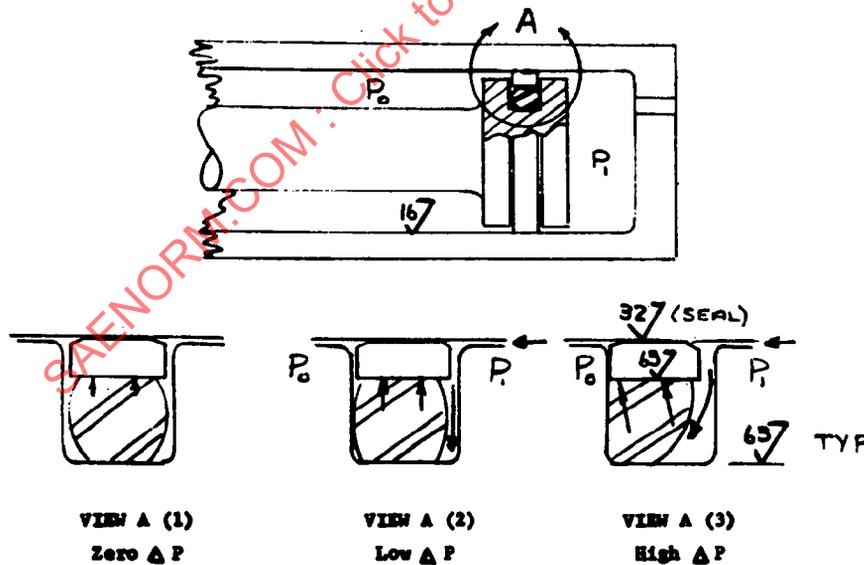


FIGURE II.

For purposes of illustration, assume that P_0 is less than P_1 . There are three possible leak paths. One is between the Slipper Seal and the cylinder wall, another is between the Slipper Seal and the O-Ring and the third is between the O-Ring and the bottom of the groove. The rate of leakage is a function of the fluid pressure, fluid viscosity and the quality of surface conditions at each leakage path.

If the quality of the surface conditions at each leakage path is sub-standard - that is, rough, nicked, scratched or contaminated with foreign particles - minute orifices exist that permit leakage. Assuming constant viscosity, leakage through an orifice is proportional to ΔP across the orifice. If the surfaces of potential leakage paths, such as are present in a typical Slipper Seal construction, could be matched perfectly, leakage would be zero regardless of the pressure, since no passage would exist. There are, of course, practical limits to the achievement of this ideal sealing condition. It can be approached very closely, however, by selecting seal materials that are deformable under stress, such as rubber and TFE. Although TFE is deformable under compressive load, it is a higher compressive modulus material than rubber and is therefore less forgiving of surface imperfections or contamination. This is particularly true at low fluid pressure when deformation due to compressive stress is low.

When imperfection on the TFE surface causes greater than allowable leakage, a brief running-in or application of high pressure will often result in improved surface to surface conformity and therefore better leakage control.

Fillers added to TFE improve wear resistance and further decrease deformation under load. This can have an adverse effect on leakage control if not accommodated in design concept, detail and workmanship.

For consistent sealing performance, a Slipper Seal must have an interference fit on the bore or rod. A good rule of thumb for the minimum interference is .001 of an inch per in. of diameter or .002, whichever is greater. Greater diametral interference is often used effectively. Consult your Slipper Seal supplier for specific recommendations.

4.3 Why are Slipper Seals Used? Slipper Seals are specified in hydraulic and pneumatic fluid power components as adjuncts to O-Rings, and alternatives to piston rings and other types of packing to realize:

1. Reduced Seal Friction
2. Longer Seal Service Life
3. Reduced Space and Weight of Hardware

5. COMMERCIAL STANDARDS ARE AVAILABLE

There are many commercial sources for TFE and filled TFE Slipper Seals. Usually the trade names used for Slipper Seals by the manufacturer are proprietary. Many of the commercial standards in use are interchangeable with respect to gland fit but vary in design detail. Some designs are proprietary and available from only one source.

Most commercial Slipper Seal standards are classified for size with the same dash number as is carried by the O-Ring for the applicable nominal rod or bore size. Except for some proprietary designs the Slipper Seal dash number and dash number of the O-Ring with which it is used are the same.

Slipper Seals are further identified as either I. D. (rod) seals or O. D. (piston) seals. An additional description for groove width may be necessary if the design is for use with either a no back-up width, one back-up width or two back-up width gland in accordance with one of the Revisions to MIL-P-5514.

The current Military Specification for O-Ring glands is MIL-G-5514F. Slipper Seal designs for glands per this current specification are interchangeable with some Slipper Seals designed for earlier revision of this specification. Slipper Seals designed for MIL-P-5514 Revisions C, D and E glands are interchangeable with each other and with some designs for other Revisions. Slipper Seals designed for MIL-P-5514A and B are interchangeable with each other and with some designs for later Revisions of the specification. The Slipper Seal supplier is the best source of information on the interchangeability of his products.

As in the case of O-Rings, up to three cross-sectional sizes of Slipper Seals are available for some diameters. In general, the dynamic O-Ring sizes are recommended for the same advantages offered by a larger O-Ring cross-section. Space and reduced hardware weight along with improved installation characteristics and reduced friction can be distinct advantages in favor of reduced cross-section (static) sizes. One important consideration is that the O-Ring is in a static environment and therefore not exposed to torsional forces, thus eliminating one of the advantages of larger cross-section. The choice between a large or a small cross-section is largely a case of judgement since environments vary widely. "Don't send a boy to do a man's job," and vice versa.

5.1 Slipper Seals for No Back-Up Width Glands per MIL-P-5514 and MIL-G-5514: These types of Slipper Seals provide anti-extrusion protection for the packing without using the extra groove length necessary to accommodate back-up rings. Typical preferred uses include spool valve sleeves and swivel glands as well as rod and piston seals for actuators.

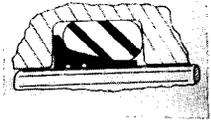
Four basic configurations of Slipper Seal-packing combinations are available as commercial standards to fit this size groove.

	<u>DESCRIPTION</u>		<u>RATING</u>
I	<u>CAP STRIP</u>		
	I. D. and O. D.		Friction Advantage vs. O-Ring
(a)	May not stay in place during assembly.	No Back-Up Width Gland	Static GOOD Dynamic FAIR
(b)	May tip in groove during use.		Service Life vs. Other Slipper Seals FAIR
(c)	Gland dimensions impose high occupancy which increases unit loading on Slipper Seal and reduces friction advantage of the TFE.		Leakage Characteristics GOOD Recommended for New Design NO
II	<u>SQUARE SEAL</u>		
	I. D. and O. D.		Friction Advantage vs. O-Ring
(a)	May not stay in place during assembly.	No Back-Up Width Gland	Static FAIR Dynamic POOR
(b)	Will not tip in groove during use.		Service Life vs. Other Slipper Seals FAIR
(c)	Gland dimensions impose high occupancy which increases unit loading on Slipper Seal and reduces friction advantage of the TFE.		Leakage Characteristics GOOD Recommended for New Design NO
III	<u>CHANNEL SEAL</u>		
	I. D. and O. D.		Friction Advantage vs. O-Ring
(a)	Will stay in place during assembly.	No Back-Up Width Gland	Static FAIR Dynamic POOR
(b)	Will not tip in groove during use.		Service Life vs. Other Slipper Seals GOOD
(c)	Gland dimensions impose high occupancy which increases unit loading on Slipper Seal and reduces friction advantage of the TFE.		Leakage Characteristics GOOD Recommended for New Design YES

5.1 Slipper Seals for No Back-Up Width Glands per MIL-P-5514 and MIL-G-5514: (Continued)

	<u>DESCRIPTION</u>		<u>RATING</u>
IV	<u>PROPRIETARY CAP STRIP</u>		
	I. D. and O. D.		Friction Advantage vs. O-Ring
(a)	Will stay in place during assembly.	No Back-Up Width Gland	Static.....EXCELLENT DynamicEXCELLENT
(b)	Will not tip in groove during use.		Service Life vs. Other Slipper Seals. EXCELLENT
(c)	Thick web improves service life.		Leakage CharacteristicsGOOD
(d)	Reduced volumetric occupancy in groove reduces friction.		Recommended for New Design..... YES
(e)	Special elastomeric seal required.		

5.2 Slipper Seals for One Back-Up Width Glands per MIL-P-5514 and MIL-G-5514: When specifying Slipper Seals for a one back-up width gland the choice of basic configurations is limited. Space is a consideration over the two back-up width gland. The possibility of replacement with an O-Ring and/or back-up in the field is a factor in preference to the no back-up width types. Retrofit requirements often dictate the use of these types of seals.

	<u>DESCRIPTION</u>		<u>RATING</u>
I	<u>CHANNEL SEAL</u>		
	I. D. and O. D.		Friction Advantage vs. O-Ring
(a)	Used on rod and piston of linear actuators.	One Back-Up Width Gland	Static.....GOOD DynamicGOOD
(b)	Gland dimensions are favorable for limiting the effect of occupancy on friction.		Service Life vs. Other Slipper Seals... EXCELLENT
			Leakage Characteristics.....GOOD
			Recommended for New Design..YES
II	<u>PROPRIETARY SEAL</u>		
	I. D. and O. D.		Friction Advantage vs. O-Ring
(a)	Primarily for rod applications on linear actuators.	One Back-Up Width Gland	Static GOOD Dynamic FAIR
(b)	Seals in one direction only.		Service Life vs. Other Slipper Seals... EXCELLENT
			Leakage Characteristics..... EXCELLENT

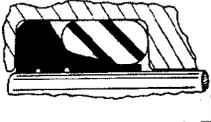
5.2 Slipper Seals for One Back-Up Width Glands per MIL-P-5514 and MIL-G-5514: (Continued)

<u>DESCRIPTION</u>	<u>RATING</u>
(c) Gland dimensions impose high occupancy which increases unit loading on Slipper Seal and reduces friction advantage of the TFE.	Recommended for New Design.....YES
(d) Seal contour improves leakage characteristics but tends to increase friction out of proportion with increase in fluid pressure.	

5.3 Slipper Seals for Two Back-Up Width Glands per MIL-P-5514 and MIL-G-5514: There are three basic Slipper Seal configurations for two backup width glands. Some types are for general purpose applications and others are intended for special purposes.

<u>DESCRIPTION</u>	<u>RATING</u>
I	
<u>CHANNEL SEAL</u>	
I. D. and O. D.	 Friction Advantage vs. O-Ring
(a) Web cracking and folding shorten life.	Static.....GOOD Dynamic.....GOOD
(b) O-Ring may be damaged adjacent to bottom of leg.	Service Life vs. Other Slipper SealsPOOR
(c) Gland dimensions are favorable for limiting the effect of occupancy on friction.	Leakage Characteristics.....GOOD Recommended for New Design..... NO
II	
<u>CHANNEL SEAL</u>	
I. D. and O. D.	 Friction Advantage vs. O-Ring
(a) This seal is in wide general use for rod and piston application on linear actuators.	Static.....GOOD Dynamic.....GOOD Service Life vs. Other Slipper Seals. EXCELLENT
(b) Gland dimensions are favorable for limiting the effect of occupancy on friction.	Leakage Characteristics..... GOOD Recommended for New Design..... YES

5.3 Slipper Seals for Two Back-Up Width Glands per MIL-P-5514 and MIL-G-5514: (Continued)

<u>DESCRIPTION</u>		<u>RATING</u>
III <u>PROPRIETARY SEAL</u>		
I. D. and O. D.		Friction Advantage vs. O-Ring
(a) Used Primarily as a rod seal	Two Back-Up Width Gland	Static.....GOOD Dynamic..... FAIR
(b) Seals in one direction only.		Service Life vs. Other Slipper Seals EXCELLENT
(c) Gland dimensions are favorable for limiting the effect of occupancy on friction.		Leakage Characteristics.....EXCELLENT
(d) Seal contour improves leakage characteristics but tends to increase friction out of proportion with increase in fluid pressure.		Recommended for New Design..... YES

5.4 Slipper Seals Requiring Special Glands: Some Slipper Seal design features have been used effectively, which preclude fitting the seal to a standard O-Ring gland.

<u>DESCRIPTION</u>		<u>RATING</u>
I <u>CAP STRIP</u>		
I. D. and O. D.		Friction Advantage vs. O-Ring
(a) Gland less than width of no back-up groove and depth of groove greater than standard to permit narrow, thicker cap.	Special Width Gland	Static..... EXCELLENT Dynamic..... EXCELLENT
(b) Will not tip in groove during use.		Service Life vs. Other Slipper Seals... EXCELLENT
(c) Easy to install.		Leakage Characteristics.....GOOD
(d) Simplicity reduces cost.		Recommended for New Design.....YES
(e) General purpose use.		

5.4 Slipper Seals Requiring Special Glands: (Continued)

<u>DESCRIPTION</u>	<u>RATING</u>
II <u>CAP STRIP</u>	
I. D. and O. D.	Friction Advantage vs. O-Ring
(a) Standard gland width but depth of gland greater than standard to permit thicker cap.	No Back-Up Width Gland
(b) Will not tip in groove during use.	Static.....GOOD Dynamic.....GOOD
(c) Easy to install.	Service Life vs. Other Slipper Seals.....GOOD
(d) Simplicity reduces cost.	Leakage Characteristics.....GOOD
(e) General purpose use.	Recommended for New Design.....YES
(f) Preferred for low speed rotary applications.	
III <u>FOOT SEAL</u>	
I. D.	Friction Advantage vs. O-Ring
(a) Special gland required in same width as two back-up. Two piece gland preferred but can be used in a one piece gland in some sizes.	Two Back-Up Width Gland
(b) Widely used as a rod seal.	Static.....GOOD Dynamic.....FAIR
(c) Seals in one direction only.	Service Life vs. Other Slipper Seals ..EXCELLENT
(d) Seal contour improves leakage characteristics but tends to increase friction out of proportion with increase in fluid pressure.	Leakage Characteristics.....EXCELLENT
	Recommended for New Design.....YES

6. FACTORS INFLUENCING THE FRICTION PERFORMANCE OF SLIPPER SEALS

- 6.1 Seal Material and Friction: Virgin unfilled TFE has a lower coefficient of friction than any filled TFE. A choice of TFE Slipper Seal material with respect to friction is of minor importance except in the most friction-sensitive applications. In those cases testing is recommended.
- 6.2 Rod and Bore Materials and Friction: Within the range of an 8 to 16 RMS finish and a lubricated surface, if steel friction factor is 100, then chrome plate friction factor will be 60 and hard anodized aluminum friction will be 120 between surfaces having relative motion.

- 6.3 Rod and Bore Finishes and Friction: Transfer of a minute layer of TFE from the Slipper Seal to the metal surface reduces friction. A finish of 8 to 64 RMS is optimum to take advantage of this phenomenon. A finish of 20 to 64 may cause leakage.
- 6.4 Lubrication and Friction: Lubrication significantly reduces Slipper Seal friction. Some leakage is desirable to realize lower friction.
- 6.5 Radial Squeeze and Fluid Pressure and Friction: Radial squeeze of the O-Ring increases the unit loading. This is in addition to the unit loading caused by fluid pressure. The higher the unit loading the higher the friction. Changes in radial squeeze will have the most significant effect at low fluid pressures.
- 6.6 Diametral Clearances and Friction: Extrusion of the Slipper Seal into a diametral clearance can increase friction dramatically due to high unit loading locally in the vicinity of the extrusion.
- 6.7 Temperature and Friction: The coefficient of friction of TFE is not affected by temperature change. However, the loading of the seal against the sealed surface may change due to temperature because of a differential linear expansion and contraction of the metal and seal components. This influence on seal friction is small and may be ignored.

Although friction is not affected significantly by differential linear expansion with temperature, volumetric changes of the seal in the groove is another story. An O-Ring/Slipper Seal combination with satisfactory friction characteristics at room temperature may have very high friction at higher temperatures if adequate room for expansion in the groove is not provided.

- 6.8 Seal Cross-Section and Diameter and Friction: The total seal friction is a function of the area acted on by the unit loading due to squeeze and fluid pressure. For a given seal diameter, a lower friction will be realized by selecting the smallest seal cross-section available.

7. FACTORS INFLUENCING THE LEAKAGE PERFORMANCE OF SLIPPER SEALS

- 7.1 Damage and Leakage: The most frequent cause of poor leakage performance is Slipper Seal damage, usually from unskilled installation procedures and handling. Installation tools and procedures to prevent seal damage are described in paragraph 9.

Axial nicks and scratches will cause leakage. Usually they can be removed successfully by circumferential sanding and/or application of high fluid pressure to the seal assembly while installed. Cycling under pressure will wear-in the seal and improve leakage performance.

- 7.2 Workmanship, Material Defects and Leakage: Slipper Seals should have a 32 RMS maximum finish on the sealing surface and a 64 RMS maximum on the surface next to the O-Ring. Minor radial grooves are acceptable on all surfaces. Cracks and inclusions may cause leakage. Slipper Seals often are stretched and folded during installation. Tensile and elongation properties should equal or exceed the manufacturer's specification or other applicable physical property control. Refer to Specification MIL-R-8791C for guidance.

- 7.3 Radial Squeeze and Leakage: Increased radial squeeze will reduce low pressure leakage.

- 7.4 Diametral Interference and Leakage: All Slipper Seals should have positive diametral interference for good leakage control.

- 7.5 Circumferential Grooves and Leakage: Circumferential grooves on the sealing surface of a Slipper Seal will improve low pressure and low viscosity leakage.

- 7.6 Material and Leakage: Unfilled TFE will give better new seal leakage performance than a filled TFE because of its greater deformation under load. Filled TFE materials may be less responsive to wear-in cycling.

- 7.7 Side-Wall Notches and Leakage: Slipper Seals depend upon pressure response to seal effectively. All O. D. Slipper Seals exposed to sudden reversal of pressure should have side-wall notches to ensure rapid pressure response if other means to admit fluid pressure into the groove are not provided. Additionally, there should be adequate side clearance between the walls of the groove and the radial side of the Slipper Seal. Massive leakage (blow-by) across the top of a Slipper Seal will be avoided if these features are included in the design. Reference Proposed AIR No. 1243 "Anti-Blow-By Design Practice For Slipper Seals."

Rod seals are not susceptible to blow-by if adequate side-wall clearance is provided.

- 7.8 Length of Stroke and Leakage: Long stroke actuators are more vulnerable to rod leakage than short stroke actuators. Most of the leakage occurs at low pressure during extension. This leakage can be reduced by using a relatively high radial squeeze rod seal.
- 7.9 Surface Finish of Hardware and Leakage: A surface finish less than 8 RMS may result in excessive leakage due to the limiting effect of the smooth surface on seal wear-in. Finishes greater than 20 RMS may cause leakage.
- 7.10 Temperature and Leakage: The ratio of the linear coefficient of thermal expansion of TFE to aluminum and steel is 7 and 10 respectively. At low temperature piston seals will try to shrink away from the cylinder wall but will be restrained by the supporting O-Ring. Leakage may occur in proportion to fluid pressure differential depending upon the temperature and the low temperature properties of both the O-Ring elastomer and the fluid. Increased O-Ring squeeze improves low temperature leakage.

Rod seals shrink onto the rod and maintain contact, minimizing low temperature rod seal leakage. However, the O-Ring used to load the Slipper Seal must have adequate low temperature properties.

High temperature fluid degradation deposits (gum) may coat surfaces over which the Slipper Seal must ride. This happens, for example, with kerosene fuel at 315 F to 350 F. Scrapers are recommended to clean the surface to ensure proper sealing.

8. FACTORS INFLUENCING THE SERVICE LIFE OF SLIPPER SEALS

Service life is usually measured in terms of leakage. When a new seal is properly installed, it can be assumed to have satisfactory leakage performance; after it is in use the leakage performance tends to improve during a break-in period and then gradually deteriorates due to wear and extrusion.

- 8.1 Material and Service Life: Filled TFE has more wear and extrusion resistance than unfilled TFE. Some proprietary unfilled TFE Slipper Seal compounds are available with wear resistance equal to some filled TFE and the deformation properties close to an unfilled TFE for better sealing. The performance of proprietary materials may vary. Claims should be verified before specifying their use. The primary advantage of filled TFE can be realized at elevated temperatures (over 275 F) and pressure (over 3000 psi). The most commonly used fillers are:

- (a) 15% Glass Fibre
- (b) 10% and 15% Graphite
- (c) 40% and 60% Bronze Powder

- 8.2 Surface Finish of Hardware and Service Life: Finish of the metal surface should not exceed 16 RMS for good seal life.

- 8.3 Temperature and Service Life: Both the TFE and elastomer materials suffer reduced physical properties at elevated temperature.

TFE Slipper Seals are more resistant to the effects of temperature than rubber O-Rings. Although TFE will soften with increased temperature, up to 550 F, there is no permanent heat damage. O-Rings, however, harden and crack at these temperatures depending upon length of exposure.